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Digital Paleography: Using the Digital Representation of Jawi Manuscripts to Support Paleographic Analysis

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Abstract— **Palaeography is the study of ancient handwritten manuscripts to date the age and to localize ancient and medieval scripts. It also deals with analysing the development of the letters shape. Ancient Jawi manuscripts are one of the least studiedarea. Nowadays, over 7789 known Jawi manuscripts are kept in custody of various libraries in Malaysia. Most of these manuscripts were undated with unknown authors and location of origin. Analysing the different types of writing styles and recognizing the manuscript illuminations can discover this important information. In this paper, we discuss the palaeographical analysis from the perspective of computer science and propose a general framework for that. This process involves investigation of Arabic influence on the Jawi manuscript writings, establishing the palaeographical type of the script, and classification of writing styles based on local and global Jawi image features.**

Keywords—**Digital PaleographyJawi, features extraction, features classification, Jawi manuscripts**

I. INTRODUCTION

System for Palaeography Inspectors (SPI) is the first digital palaeography for medieval manuscripts developed in 1999 by a group of researchers in University of Pisa[1]. However, the SPI is not used by the History Department in the university because the implementation is not completed. The SPI imitated the behaviour of palaeographers in order to classify documents into several categories. It used local features for training the palaeographical database and for classification purposes to assist palaeographers in analysis of medieval manuscripts. Based on the SPI, [2]presented different approach to analyse ancient manuscripts. A statistical approach based on 12 haralick features to identify type of font in the manuscripts was proposed in [2].Global features from ancient manuscript are used to figure out the type of writing style applied in the manuscripts. This approach is better compared to SPI; however, still suffers some weaknesses. Although global approach looks more practical for not requiring manual or automated segmentation either in letter or word level, there is still a problem with its statistical approach. The statistical approach tends to categorise the manuscripts into one category although theymay contain more than one style of writing [2], [3]. This paper will come out with a framework for Digital JawiPalaeography that covers the local, global and hybrid features.

Previously, preliminary work on Digital JawiPalaeographyhas been done resulting in two papers published locally and internationally. The papers are [4] and [5]. The papers come out with research on Palaeography done for Roman, Indian, Hebrew and Arabic scripts. The papers also propose Research Methodology for Digital Jawi Palaeography and a framework for Digital JawiPalaeography.

The Digital Jawi Palaeography is important due to thevast number of Jawi manuscripts in Malaysia,that is, around 7789 [6]. Some of the manuscripts are of unknown date, place of origin and authors, for example, in the book of "Undang-undangMelayu" [7]. Study of the book revealed the possibility that it was written by three different authors, followingdifferent types of Arabic calligraphy applied to the manuscript[7]. This is also supported by[3]based on his research to the manuscript "MerongMahawangsa", which found four different types of Arabic calligraphy in the Manuscript.

With the number of manuscripts in Malaysia, some of unknown date, place of origin and authors, it is a good point to digitize Jawipaleography into digital form. Until to date, there is no Digital JawiPaleography that can help paleographers and Malay curators. This is supported by [8] and[9]. These include local research published in JurnalFiologi(2006). [8], [9] and [10] identified the date and the origin of the Jawi ancient manuscripts based on the codicological features manually. However there did exist digital paleography system for Latin manuscripts that was developed in 1999.

The system,namely System for Paleography Inspectors (SPI),was developed by a group of researchers in University

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of Pisa. The purpose was to assist paleographersin analysis of Latin ancient manuscripts. The research was led by Prof. Alessandro Sperduti and Prof.AntoninaStarita. However, its implementation was never completed, hence not used by Latin based paleograpers[1].

II. Brief on Palegraphy

Palaeography is the study of ancient handwritten manuscripts(Yosef et al. 2004). It also defined as the art of seeing and understanding, the study of historic script including their adjuncts and the interpretations. Paleography also deals with identifying the date and place of origin of ancient manuscripts(Brown 1994). Sijpesteijn (2008) cited from (Witkam 2009) that, paleography is a science of identifying date of ancient manuscripts. In Witkam (2009), the meaning of paleography in the western context is also applicable in the Arabic context. Hence Arabic paleography is the study of the time and place properties in Arabic scripts.

Nowadays, the common method used by paleographers expert is graphic comparison. It is done by comparing each graphic against a dated and localised corpus[1]. This approach required a good knowledge on the provenance and textual tradition, its decoration and illumination that are commonly found in Roman manuscripts [1]. These factors also can be found in ancient Arabic and Jawi manuscripts. However, the Arabic and Jawi manuscripts were tightly influenced with calligraphy.

The purpose of the method mentioned above is to allow paleographers to identify unconsciously idiosyncratic aspects of a scribe's individual style— providing indispensable clues for establishing the identity or non-identity of unknown hands [1].

With the factors mentioned and methods used by paleograpers are valuables input to the Digital paleography that was developed by the by Prof. Alessandro Sperduti and Prof. Antonina Starita[1] and for the recent researches in the domain digital paleography.

III. Digital Paleography

Paleography is a subset of the research in digital handwriting. However, this research focuses on ancient manuscripts with missing date and place. The purpose of digital paleography described by [1] is to use digital representation of book hands as a tool to support paleographical analysis by human expert. It works by describing certain graphics style of handwriting and then compare it with different scripts in relation to geographical and chronologicalaspcts[1]. Hence, the SPI was developed by imitating the behaviours of paleographer in order to do paleography analysis.

Until to date, researches of digital paleography were made on Roman, Indian, Hebrew, Arabic and Farsi handwritten scripts. Researches in Roman script were made by [11], [12],[13], and [14]. Researches in Indian handwriting were done by[15],[16]. Researches in Hebrew handwriting done by[17]. Arabic scripts are divided into scripts in Arabic language and Farsi language. [18]and [19]did the research on Farsi handwriting, whereras, [20], [13], [21], [22], [23], [24] did research on Arabic handwriting. Most of the researches aim to recognize the type and style of writing and also paleography. Among these researches, on identifying writers are more popular than paleography researches.

Although the research on identifying writers based on handwritten documents were done by many researchers, but contributions to paleography are not significant[2]. Based on his research on Latin manuscripts, the type of writing always change due to the usage. According to him, from VIII to XI century, the Caroline was widespread in the West and the Gothic was used in the North Europe. The change from one writing to another was made through a slow and progessive evolution. Hence, the complexity to identify the category of writing in the ancient manuscripts had increased.[2], [1] proved that manuscripts that were written using the Caroline type had elements of the Gothic.

According to him, the evolution of writing is from the Caroline to the Cursive Gothic then to the Batarde Gothic and the fnally to the Textualis Gothic. The evolution of writing gives complexity to Latin paleographers as well as Arabic.

IV. Factors for Digital Jawi Paleography

In the Islamic civilizations, there are many types of Arabic calligraphy. The popular ones are Kufi, Riq'ah, Nas'akh, Diwani, Diwani Jali and Raihani[25],[3] and [26]. Each type of calligraphy was introduced in a different place and time. The Kufi was created in Kuffah and became the standard style for writing Al-Quran from the 8th century for 300 years. The Naskh was developed in the 10th century and was updated in the 16th century in Turkey. It has becomethe standard for writing Al-Quran until now. Other types of calligraphy like Nastaliq or Farsi was created in the 14th to 15th century in Iran. Uniquely, each type of arabic calligraphy was born in different century and places.

Jawi shared a same characters with arab character with few additional characters that based on current characters to support pronounciations in Malay language [3] and [27]. Due to the characters that based on arabic word, it is also be influenced by the arabic callography. This was supported by a research done by [3] on the Merong Mahawangsa manuscipt found that the skew and slant of jawi handwriting was influenced by the type of writing used, which is referring to the type of arabic calligraphy. According to him, three different types of arabic calligraphy existed in the manuscript. They are Nasakh, Thuluth and Riq'ah. This finding can give useful input to the research of jawi paleography.

Besides, the book "Undang-undang Melayu", according to[7], was written by three different authors. It is based on the occurance of different types of arabic calligraphy in the book in page 1-10, 11-16 and 17-32. According to him, the first part in page 1-10, Nasakh and Thuluth were used. But the author did not use standard Nasakh and Thuluth. The writing style was shorter than usual and had circular-shaped like Jawa or sanskrit writing. The second part contains Thuluth and in the third part, the writing shape had became moresquarly shaped.

The result of date and the origin of calligraphy is useful in a wide area of applications[25].The influences of arabic calligraphy in the Jawi manuscripts is one of the factors that influence theJawi Paleography. The technical features or

codicological features of calligraphy can be used to identify the type of calligraphy used.

From the perspective of digital paleography, studied manuscripts in existing researches such as[8] and [9] were not in digital form. These include local research published in Jurnal Fiologi(2006). The researchers identified the date and the origin of the Jawi ancient manuscripts based on the codicological features manually.

Based on the observe facts, it is crucial to do a digital Jawi Paleography. It will help us in dating Jawi manuscripts, identfying type of writing and the origin of the manuscripts without the presence of paleographers.

This need is supported by[7]. According to him, existing manuscripts were mostly unknown. It is based on his research on the book of "Undang-undang Melayu" that was written in the middle of 18th century. There are 7789 collected Jawi manuscripts in Malaysian collection. Perpustakaan Negara Malaysia, Perpustakaan Universiti Malaya, Perpustakaan Tun Sri Lanang, Dewan Bahasa dan Pustaka and Muzium Seni Islam Malaysia have 3699, 397, 57, 226 and 3500 manuscripts respectively[6]. With the number of manuscript stated, the need for digital Jawi paleography is undoubtly high in order to identify the type of writing, dating, and the origin of manuscripts.

The ancient Jawi manuscripts contain a lot of historical information, both implicit and explicit. The previous paragraphs discuss about the implicit information obtained from the style of writing.The style of writing can give plenty of information about paleograpy.In addition, the illuminations or decoration of pages can also contribute to the study. Illumination is the decoration art of books or manuscripts using precious material, particularly gold and silver. Early manuscripts were decorated to make the text more interesting and understandable [28]. According to him, the illumination styles also potray information regarding to the era when it was written. Hence, the digital Jawi paleography should not cover only the writing style but the illumination as well.

To realise the digital jawi paleography, the techniques used by researchers in image processing and specifically in indentifying writers from unknown documents can be used because the techniques can extract features from handwritten images as input for classification process resultng in identification of writers. Besides, techniques used by other writing style like Latin, Hebrew, Indian and Arabic will be studied. Some examples will be stated and the processes of identifying style of writing that is a part of paleography will be explained.

V. IMPORTANCE OF RESEARCH IN PALEOGRAPHY

The digital Jawi Paleography research can produce valuable information to us. Through this research, the information below can be identified:

1) the originality
2) number of writers
3) type of writing (type of arabic calligraphy occurs in manuscripts)[15] and[9],
4) the origin of manuscripts [15] and[15],
5) date of written or range of years [2]

The list was obtained from [2]with some adaptations to fit to Jawi ancient manuscripts.

VI. EXISTING DIGITAL PALEOGRAPHY RESEARCHES

A SPI system that was developed in 1999 is the first digital paleography for Roman manusricpts. Unfortunately, the system is not completed and has not be used by the Historical Department of Pisa University [17].

The purpose of SPI is to assist paleographer to do analysis on medieval manuscripts. It works by imitating the behavior of paleographers by identifying some special features on selected text images and type of writing style in manuscripts. The images then are compared to the data in the Paleographical Database.

The SPI required continuous script to be segmented to individual letterforms. Then, features will be extracted that named as centryod and tangents. The SPI will do the dendogram that is clustering model in subsets and orders them in a hierarchical order.

The proses of analysis the medieval manuscripts by SPI is as shown in Fig. 1 below.

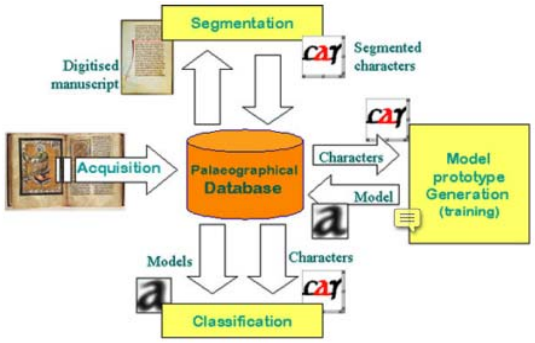

Fig. 1 Model for the SPI System

Paleography research for Roman was done by[2]. He classified the manuscripts into 14 categories and each category represents one time interval. The processes that was used can be presented in**Fig. 2** below.

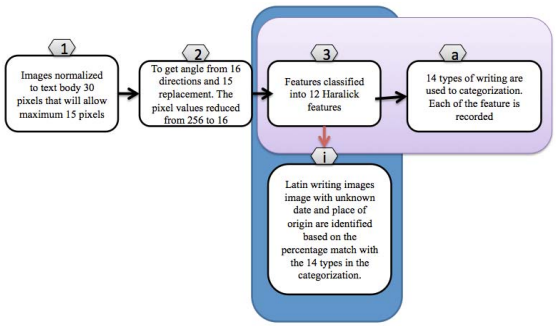

Fig. 2 The Summary of Model [2]

[2]has set the specific type of images. The text images have been taken without considering whole page. He used Spatial Gray-Level Dependence (SGLD). Twelve Haralick Features were extracted from the SGLD. The features used to identify type of writing based on awriting versusFeature mapping table. Hit for each features is equivalent to percentage of

occurance in the image. The Haralick Features that were used is shown in Table 1below:

TABLE 1

HARALICK FEATURES

	Type of Haralick Features		
f1	Angular Second Moment(ASM) Homogeneity	f7	Sum Varians
f2	Element Difference Moment	f8	Sum Entropy
f3	Correlation	f9	Entropy
f4	Varians(VAR) (Sum of Squares)	f10	Difference varians
f5	Inverse Difference Moment(IDM)	f11	Difference entropy
f6	Sum Average	f12	Entropy Measure

[17]researched on Hebrew handwritten and classfified the writing to the Hebrew calligraphies. He did processes shown in Fig. 3below.

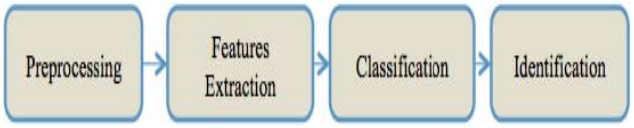

Fig. 3The Classification Methodology of Hebrew Style by [17]

For explanation of[17], [17]said, the quality of ancient manuscripts degrades through time. Thishas also been verified by a Jawi researcher that studies on repairing the quality of jawi manuscripts with background damage [17]. In the preprocessing phase, [17]has used binarization method. After the preprocessing process he used Multi-Stage Thresholding method. In this method, he applied global tresholoding followed by irrelevant objects discarding, followed by local componentsprocessing and the post processing. The purposes of each stage are explained in the Table 2 below.

TABLE 2

MULTI-LEVEL THRESHOLDING

Steps	Purposes
Global Thresholding	To narrow the search space foreground candidatesto produce spatial information on text lines and characters
Discarding irrelevant objects	Pixels that are not belonging to text lines will be deleted apply connected component labelling and split
Local component processing	Get the threshold based on the foreground grayscaleget the candidate pixels from background image that connected to foreground image
Post-processing	Filling small holes

Features used by this researcher are dominant background sets from connected components.

Paleography researches was also had been done by Indian researchers. They used global approach in identifying the type of writing in documents. Although their research did not mention about paleography but it contributes to the study of paleography. The Fig. 4 below shows the model used by[16]:

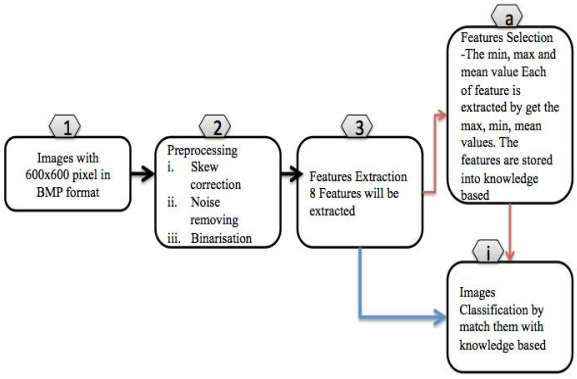

Fig. 4 The Model of [16]

Features used by [16]as shown in Table 3 below.

TABLE 3

FEATURES BY [16]

	Features
1	Bottom-max-row-no
2	Top-horizontol-line
3	Tick-top
4	Bottom-component
5	Top-pipe-size
6	Bottom-pipe-size
7	Top-pipe-density
8	Bottom-pipe-density

Besides[16], this paper discusses about general framework introduced by[16]. The classifiers by [15] is divided into three level of features extraction that based on Log Bank Gabor Filter. The first classifiers named as features level one, the second named features level two and the last is vertical projection. [15]introduced the model shown in Fig. 5below.

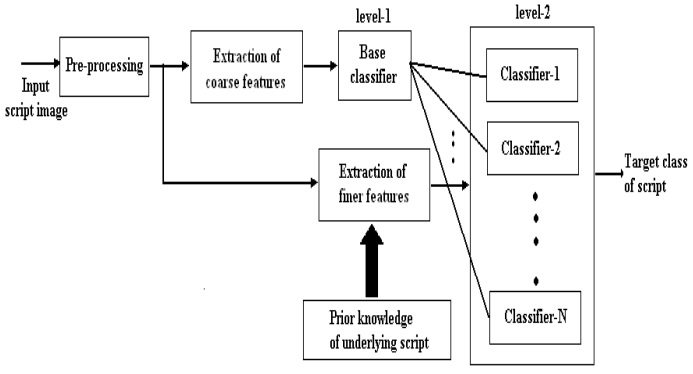

Fig. 5 Model (Joshi et al. 2007)

Table 4 below shows features level one and level two used by these researchers.

TABLE 4

FEATURES FROM LOG-GABOR FILTER

	First Level Features (Coarse Features)	Second Level Features
1	Energy profileE(θi); i=1,...8for all 10 indian scripts	Ratios of normalised energies $R = (i,j) = E(\theta i)/ E(\theta j)$
2	Relative strength in adjacent orientation. $\Delta Ei; 1,...8$	

VII. COMPARISON OF IMAGE PROCESSING TECHNIQUES IN PALAEOGRAPHY

Table 5 shows the summary of techniques used by researchers in paleography study. All aspects of researches of writing have been studied. The comparison is stated in the table 5. Only one approch uses local approach and the rest uses the global approach.

TABLE 5

THE COMPARISON OF PALEOGRAPHY TECHNIQUES

	Latin Scripts [1]	Latin Scripts [2]	Hebrew Scripts [17]	Indian Scripts [16]	Indian Scripts [15]
Approach	Local	Global	Local	Global	Global
Features	Centroid and tangents	12 Haralick Features	Background region from connected components	8 features extracted from writing line	Features from Log-Gabor Filter and divided into 2 levels
Algorithms	Not stated	Spatial Gray-Level Dependence (SGLD) Dan Hiralick	Multi-level Thresholding	Not stated clearly	Log-Gabor Filter
Results	The posible category of character for the selected input	Hit in percentage of 14 categories	Type of Lamed and Aleph are identified from manual selection.	Hit in percentage for 8 categories	Graph Energy vs. Error rate

The important part in identifying type of writing and dating is the features extraction from the manuscripts images. Each feature contributes to classifier process. The classifiers are used to identfy manuscripts that are based on the extracted features.

The type of writing is identified based on the percentage of occurance of selected features in the classifiers. Based on the type of writing, date and time scale of manuscript can be identified[2].

VIII. DIRECTION OF JAWI DIGITAL PALEOGRAPHY RESEARCH

The direction of Jawi digital paleograpy using image processing can be extended to the comprehensive studies based on the factors below.

TABLE 6

LOCAL AND INTERNATIONAL PALAEOGRAPHERS EXPERT

Researchers	Location	Publications	Year	Pub./ISBN
Anabel Teh Gallop	Britain	1.Beautifying Jawi: between calligraphy and palaeography, penerbit: UniversitiPendidikan Sultan Idris	2005	UniversitiPendidikan Sultan Idris, ISBN: 9834143125
		2. Ottoman influences in the seal of Sultan AlauddinRiayatSyah of Aceh (r.1589-1604)	2004	Indonesia and the Malay world, Vol. 32, No. 93, pp. 176-190
Jan Just Witkam	Universiti Leiden, Holland	The didactics of Palaeography	2009	TIMA's Workshop on Codicology, Cambridge, UK
Wan Ali Wan Mat	Malaysia	PaleografiJawi: SatuPengenalan	2006	JurnalFilologi Melayu, Jilid 14, Perpustakaan Negara Malaysia

A. Involvement of local and international organization.

There are several international organization that are actively conducting seminar, training, research grant, scolarship, publications and active website that keep on updating activity on Islamic manuscripts. On of the organization is "The Islamic Manuscript Association (TIMA)" that is located in United Kingdom. All information and seminars can be obtained from their official website http://www.islamicmanuscript.org/.

Besides TIMA, British library UK in the department of South and Southeast Asia Section also involves in the research of Malay manuscripts. There are many books published and also Malay ancient manuscripts stored in The British Library. Information about books, malay manuscripts and malaypaleography can be obtained by navigating this official websitehttp://www.bl.uk/researchregister/1.9/?app_cd=RR&page_cd=PUBLICATION&l_researcher_id=20

An other international that holds Jawi manuscripts for paleography is the University of Leiden, Leiden, The Netherlands. Therearesseveral ongoing and completed

researches on jawipaleography in this university. Further information please visit http://www.library.leiden.edu/special-collections/oriental-collections/intro-se-asia.html

For the local organization, Perpustakaan Negara Malaysia (PNM) hadmade an important role in the paleography study on Jawi manuscripts. PNM has successfully published 16 journals, in theJurnalFilologiMelayu. Further information, please visit http://www.pnm.my/index.php?id=42

B. Local and international JawiPalaeographers

Currently knownJawipaleographers at international and local level are listed in Table 6 above.
The publications stated in the Table 6 are only the publications that related to palaeography Jawi studies.

C. Palaeography and Image Processing.

In image processing, inputs from paleographers are important to identify useful features for the features extraction process, classification and to verify the accuracy of recognization done in digital form. So, academic publications related to image processing are important todevelop frameworks and algotrithms of Digital JawiPaleography. Table 7 below shows some source of references that are related to digital palaeography.

TABLE 7

REFERENCES FOR DIGITAL PALEOGRAPHY

	Publications
i.	Digital Palaeography: Using the digital representation of medieval script to support palaeographic analysis [1]
ii.	Using codebooks of fragmented connected-component contours in forensic and historic writer identification[1]
iii.	Text-independent writer identification and verification using textural and allographic features[14]
iv.	Combining global and local features for writer identification[11]
v.	Establishing handwriting individuality using pattern recognition techniques[29]
vi.	Discriminatory power of handwritten words for writer recognition [30]
vii.	Neural Networks and Support Vector Machines Classifiers for Writer Identification Using Arabic Script[24]

IX. FRAMEWORK FOR IDENTIFYING TYPE OF ARABIC CALLIGRAPHY IN JAWI MANUSCRIPTS

This proposed framework is based on analysis from previous works by paleography researchers mentioned in this paper. Researchers in identifying writers and type of writing are using global, local or hybrid features[24]. Fig. 6below shows the general framework that can be usedby Digital Jawi Researchers in classifying manuscripts.

This framework covers three types of feature category. The model provide by [1] in [1] does not cover global features and as well as global and hybrid classifiers. The SPI itself works using local features by imitating the behaviours of palaeographers.

In the proposed framework, image from manuscripts Jawi will be divided into two parts. The first part is text and the second part is illumination. The image is named as raw imagesIt is based on the nature of ancient manuscripts [28], [3].

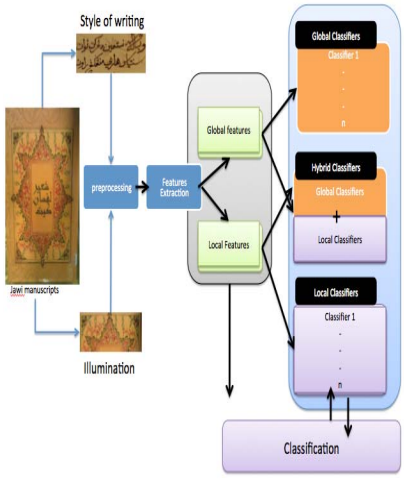

Fig. 6 General Framework for Digital JawiPalaeography

The raw image then will be processed in pre-processing stage. In this stage, raw image is converted to grey scale or binary scale in order to extract features. Features extraction stage will extract potential features that are valuable to classifiers. The features are either local or global features.

Classifier will category the features into certain group. In the digital palaeography Linear Discriminant Analysis and Principle Components Analysis are suggested be used to category features.

X. CONCLUSION

Paleography is an interesting research. From this research, implicit manuscript information can be explored. The type and style of writing, illumination in manuscripts can be used to identify the origin of manuscripts, dating, number of writers and the originality of manuscripts.

Palaeography researchers in Latin and Arabic had used features extracted from ancient manuscripts. The features can be local, global and hybrid. But, not necessarily all the features can be adapted to Jawi manuscripts. Although Arabic and Jawi share almost the same fonts but significant differencesdo exist. The pronounciations in Jawi is different and Jawi has extra alphabets that conform to the terms of Malay language.

Thus, comprehensive research to the potential features in Jawimanusrcipts can contribute to the digital JawiPaleography. In the classification phase, the features will be classified into the existing Arabic calligraphy categorisation known as the al-qalam al-sittah. There are six main categories and possibly through this research, only few of al-qalam al-sittahwere used in ancient Malay manuscripts.

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